

RESEARCH DEPARTMENT

ASSESSMENT OF NOISE IN TELEVISION:
ITS VISIBILITY OVER THE GREY SCALE

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SUMMARY

The noise characteristics of several different television picture sources are examined and conclusions are reached as to the form of the dependence (or independence) of the noise upon picture signal strength. In some cases the noise is concentrated in the darker regions of the picture whilst in others it is found more in the lighter parts; in yet a third case it is independent of picture signals.

1. INTRODUCTION

This paper attempts to clarify certain effects produced upon the visibility of random fluctuation noise due to non-linearity in the relevant portions of television transmission channels.

A television transmission includes four basic elements; the scene to be transmitted (or an image of it), the television pick-up device, the receiving picture tube and the viewer's eye. In an ideal case we shall assume that the pick-up tube transfer characteristic would be complementary to that of the picture tube, so that there would be proportionality between the brightnesses of corresponding parts of the received image on the picture-tube screen and the original scene itself. Throughout what follows we shall retain the assumption that the transfer characteristic between the scene to be transmitted and its image on the receiver picture tube is linear. In some cases gamma-control circuits are required when the pick-up tube has a transfer characteristic which is not complementary to that of the picture tube. The effect produced by these gamma-correction circuits upon the visibility of the noise and particularly upon its distribution over the grey scale of the image has given rise to some confusion.

First, the effect produced by a non-linear circuit on the noise must be understood. The change in the power spectrum of the noise caused by its passage through a non-linear circuit will be ignored because it is considered to be negligible in most television applications. We assume that the noise fluctuation is so small that its waveform is unaltered by the non-linearity of the transfer characteristics which operate upon it; this is a corollary to the previous statement. When television signal and noise are simultaneously present in a non-linear circuit the noise may be regarded as "riding upon" the signal in the manner shown in Fig. 1. Two different signal levels S_1 and S'_1 are shown accompanied by noise fluctuations N_1 and N'_1 respectively. The figure shows that, although N'_1 may have the same value as N_1 , the output fluctuations N'_2 and N_2 are by no means equal; they would be equal if the characteristic were linear.

It is well known (Weber-Fechner law) that the function relating the sensation of brightness to the objective brightness of a patch of light is of a more or less logarithmic form. Furthermore, for many practical purposes it may be taken as a simple power law or gamma characteristic. Fig. 2 shows this function plotted over a range of brightness commensurate with that found in typical television reception conditions. This curve expresses a relationship which is very close indeed to that which would describe the sensation of brightness as being proportional to the cube root of the objective brightness.

It so happens that the normal receiver picture tube has a transfer function relating screen brightness to grid voltage which approximates to a simple five-halves power law, and as this is almost complementary to the eye characteristic we may conclude that the transfer law between (subjective) sensation and picture-tube grid voltage is nearly linear or unity gamma. Thus, as pointed out by Kell,¹ equal increments of picture-tube grid voltage give rise to equal increments of sensation. It may be stated quite generally that any noise fluctuation added to the signal before its arrival at the picture-tube grid and subsequent to any non-linear circuits employed at the point of origin will appear to be evenly distributed over the grey scale of the received image. The noise produced by the first stage of the receiver as well as that introduced in the process of transmission come within this category. There are several cases in which noise originating at the television pick-up device also comes within the same category. Fig. 3 shows a schematic diagram of a typical example, in which an iconoscope (Emitron) or image iconoscope (Photicon) camera tube requiring no gamma correction sends picture signals through a linear television channel to the grid of a receiving picture tube. No gamma correction is necessary because quite fortuitously the camera-tube transfer function expressing signal current in terms of scene brightness (light input) approximates to a two-fifths power law which is complementary to the picture-tube characteristic: in this way brightness linearity from scene to receiver-screen image is maintained. Excluding fringe-area reception, the greater part of the noise visible at the reception of picture signals originating from a source such as is shown in Fig. 3 arises in the first valve in the camera head amplifier and, from what has been said, will appear to be equally visible throughout the grey scale of the received image. Experience has shown that this is, in fact, the case. The transfer functions of the various high-velocity-beam cameras and receiving cathode-ray tubes are well known; only the eye characteristic is open to question. The fact that in a transmission such as that indicated in Fig. 3 the noise does seem to be evenly distributed over the grey scale may, however, be regarded as confirming the general shape of the curve in Fig. 2.

From the foregoing it will be evident that the distribution of noise visibility depends upon the position at which the noise is inserted, the camera-tube characteristic and other factors. It will be assumed in what follows that the uniform distribution of noise visibility is the least undesirable way of presenting noise in a picture containing brightness levels within contrast ranges typical of television. Kell's experiments¹ would seem to verify this assumption.

The often-heard phrase "gamma circuits introduce noise", whilst not meant to be taken literally, nevertheless tends to remove from a picture source the onus of responsibility for a poor operating signal-to-noise ratio which remains concealed until revealed by a gamma-correction circuit. The latter may well be necessitated by considerations of picture "tone" gradation rather than signal-to-noise ratio.

To illustrate this point, consider the case of a low-velocity-beam camera such as the orthicon, (C.P.S. Emitron), Fig. 4, for which the transfer characteristic is linear. As in the previous example, first-stage noise is added after the signal leaves the camera tube, but its visibility over the grey scale will in this case be different. The signal from the camera tube is no longer proportional to the sensation of scene brightness; for it to be so, we should require a camera tube transfer characteristic having a two-fifths (or better, a one-third) power law. If, therefore, we re-plot this transfer characteristic as signal current against scene brightness in sensation units, it will have the form of a five halves (or better, a cube) law and will be relatively insensitive in the "blacks" and too sensitive in the "whites". A noise fluctuation added to the output signal will thus "disturb" the signal in the darker tones to a much greater extent than it will in the lighter tones. This will not be apparent if the picture is viewed directly on a normal picture tube, simply because the darker tones, and the noise, will be crushed. The gamma-correcting circuit which is necessary in order to compensate for the picture tube characteristic merely reveals a situation which exists at the camera output. Thus, a camera tube having a transfer characteristic which differs from that of the human eye (a one-third to two-fifths power law) will always give rise to the sensation of unequally distributed noise, if the latter is added after the camera tube. If the camera tube transfer characteristic has a higher power than that of the eye then noise will be more apparent in the "blacks" whilst a lower power law will cause it to be more visible in the "whites". An extension of this discussion will perhaps reveal the camera's responsibility more clearly. Suppose we invent a linear cathode-ray tube, that is, one in which the screen-brightness is proportional to the grid voltage. This tube used in conjunction with a linear camera tube such as the orthicon will no longer require a gamma correction circuit and yet, in spite of the absence of gamma correction, the sensation of noise will still be predominant in the "blacks". Thus, it is seen that the gamma correction circuit merely compensates for a non-linear cathode-ray tube and has no influence upon the distribution of the sensation of noise over the grey scale.

It might be remarked that notwithstanding the high (but in practice never infinite) gain at low brightness or signal levels introduced by the de-gamma circuit, if the noise level were sufficiently low it would scarcely be visible, particularly as the sensitivity of the orthicon measured in terms of $\mu\text{A}/\text{lumen}$ is greater than that of the image iconoscope. Fig. 5 will elucidate this point. Curve 1 is the transfer characteristic of an image iconoscope whilst Curve 2 is that of an orthicon. It will be seen that for a given luminous flux on to the photo-cathode and target respectively, the orthicon is the more sensitive tube and since we assume the same head amplifier, and therefore noise level, for the two tubes, the signal-to-noise ratio of the orthicon is greater. Unfortunately it is not possible to reap the full benefit of the orthicon's greater sensitivity because of target instability or "peel-off". This phenomenon occurs when the incident light flux on to the target exceeds a threshold value and thus limits the permissible amount of studio lighting to a value such that the flux arriving on the target from the brightest part of the scene does not exceed that required by the point A' in the figure. If the contrast ratio it is desired to transmit is, say, ten to one, then the "blackest black" will be represented by the point B' and this will give rise to a signal current of about $0.007 \mu\text{A}$. Now to transmit the same scenic contrast range with an image iconoscope required an altogether higher level of studio lighting, but this can easily be accomplished and gives us the operating points A and B. In this case the current

corresponding to the "blackest black" will be $0.019\mu A$ and the signal-to-noise ratio in the blacks will be two and a half times that obtained in the "dimmer" scene required for the orthicon.

The above discussion, whilst not directly relevant to a study of the distribution of the noise over the grey scale, nevertheless points to the conclusion that, in the presence of an upper limit to scene brightness, a linear camera-tube characteristic is not necessarily desirable - nor would it become desirable if cathode-ray tubes had linear transfer characteristics because the low-gamma characteristic of the eye would still intervene to raise the visibility of the noise in the "blacks".

The above discussion in qualitative terms will now be followed by quantitative analyses of several practical cases.

2. USE OF CAMERA WITH HIGH-VELOCITY BEAM

Let us consider a typical transmission using a high-velocity camera having a simple power-law transfer characteristic relating output signal to input luminance. Let us assume also that the receiver picture-tube transfer characteristic is likewise a simple power law having as its exponent the reciprocal of that of the camera tube; and lastly we shall take the transfer characteristic of the viewer's eye relating sensation units in the brain to luminance on the picture-tube screen to be the same as that of the camera tube. Fig. 3 (end of Report) shows the sequence of processes through which the signal and the noise arising in the first valve of the camera head amplifier will pass.

Let $B \propto$ scene brightness
 $S_1 \propto$ signal emerging from camera tube
 $N_1 \propto$ noise added to camera-tube output, that is, noise added to S_1
 $S_2 \propto$ signal brightness on picture-tube screen
 $N_2 \propto$ noise brightness on picture-tube screen
 $S_3 \propto$ sensation units of signal brightness in the eye
 $N_3 \propto$ sensation units of noise brightness in the eye

Fig. 2 shows that, in the absence of noise

$$S_1 \propto B^\gamma, \quad S_2 \propto S_1^{1/\gamma} \text{ i.e. } S_2 \propto B, \quad S_3 \propto S_2^\gamma \text{ i.e. } S_3 \propto B^\gamma \quad (1)$$

If we now assume that in each section of the signal chain the noise is always much smaller in amplitude than the signal, we may write

$$N_1 \ll S_1 \quad N_2 \ll S_2 \quad N_3 \ll S_3 \quad (2)$$

and the action of the gamma circuits on the signal will be unaffected by the presence of relatively small noise components; furthermore, these may be treated as differentials.

Fig. 1 shows what becomes of a signal S_1 and its attendant noise or uncertainty N_1 when these are passed simultaneously through a non-linear circuit described by one of the proportionalities 1, say

$$S_2 \propto S_1^{1/\gamma}$$

It is easy to see that the output noise N_1 may be obtained either directly by multiplying the input noise by the slope or derivative of the gamma curve at that point which is determined by the level of the input signal, S_1 , or by raising the input consisting of noise and signal to the appropriate power (e.g. $1/\gamma$) required by the exponent of the succeeding non-linear device, and then neglecting all terms other than the first two; that is, obtaining noise and signal but neglecting terms containing noise raised to powers higher than the first. Thus, using the derivative method

$$N_2 \propto N_1 \frac{dS_2}{dS_1} \quad (3)$$

and similarly, the subjective effect of the noise in sensation units will be

$$N_3 \propto N_2 \frac{dS_3}{dS_2} \quad (4)$$

If we substitute into proportionalities 3 and 4 those obtained from 1 and substitute into 4 the value of N_2 from 3 we obtain

$$N_3 \propto N_1 \quad (5)$$

This is a result of some importance, for it shows that, for the particular case we are considering, the noise sensation is independent of signal level or scene brightness. If the noise does not depend upon scene brightness it must appear as evenly distributed throughout the contrast range of the picture-tube image as stated in the Introduction.

It has already been said that this state of affairs occurs when high-velocity cameras are used. This proves that the non-linear transfer characteristic of the eye (sensation units-image brightness) must approximate to that of a high-velocity camera for which, as is well known, $\gamma \approx 2/5$.

3. USE OF CAMERA WITH LOW-VELOCITY BEAM: ORTHICON CAMERA

It is now possible to show in a simple manner how the noise in a viewed image originated by a low-velocity orthicon camera (C.P.S. Emitron) seems more perceptible in dark regions than elsewhere. In the Introduction it was explained why, in view of the greater sensitivity of the orthicon, the noise is not entirely negligible as might have been supposed.

Fig. 4 shows a typical television transmission using an orthicon camera. The noise due to the first valve in the head amplifier is added to the signal before the latter has suffered any non-linearity and thus combines with the signal at a part of the chain in which equal increments of excitation do not give rise to equal increments of sensation.

Let $B \propto$ scene brightness

$S_1 \propto$ signal emerging from camera tube

$N_1 \propto$ noise added to camera-tube output, that is, noise added to S_1

$S_{1a} \propto$ signal output from de-gamma circuit

$N_{1a} \propto$ noise output from de-gamma circuit

$N_2 \propto$ noise brightness on picture-tube screen

$S_2 \propto$ signal brightness on picture-tube screen

$S_3 \propto$ sensation units of signal brightness

$N_3 \propto$ sensation units of noise brightness

This time we have, in the absence of noise

$$S_1 \propto B, \quad S_{1a} \propto S_1^\gamma \text{ i.e. } S_{1a} \propto B^\gamma, \quad S_2 \propto S_{1a}^{1/\gamma} \text{ i.e. } S_2 \propto B, \quad S_3 \propto S_2^\gamma \text{ i.e. } S_3 \propto B^\gamma \quad (6)$$

Assuming again that the noises are small compared with their attendant signals we have

$$N_{1a} \propto N_1 \frac{dS_{1a}}{dS_1} \quad (7)$$

$$N_2 \propto N_{1a} \frac{dS_2}{dS_{1a}} \quad (8)$$

$$N_3 \propto N_2 \frac{dS_3}{dS_2} \quad (9)$$

Substituting the appropriate proportionality from 6 into 7, 8 and 9, and then substituting 7 into 8 and 8 into 9 we obtain

$$N_3 \propto \frac{\gamma N_1}{B^{1-\gamma}} \quad (10)$$

If we let $\gamma = 2/5$ which we know to be a reasonable approximation, proportionality 10 yields

$$N_3 \propto \frac{N_1}{B^{3/5}} \quad (11)$$

This shows that when using an orthicon (C.P.S. Emitron) followed by a de-gamma circuit in the camera control unit, the noise will be a function of the scene brightness B , and will be most evident in the "blacks". This is, in fact, the case.

If it were desirable and convenient to de-gamma the scene itself or at least its electronic image on the orthicon target then the situation would become the same as that described in the case of high-velocity-beam cameras, and the de-gamma circuit which had been situated after the point at which the noise was added could be removed. The noise would then appear to be uniformly spread over the entire grey scale.

4. USE OF FILM SCANNER WITH HIGH-GAIN PHOTO-MULTIPLIER³

Fig. 6 is a schematic diagram showing the processes through which the signal and noise must pass. The effect of noise due to afterglow has been omitted from this discussion. It may be seen that, using similar notation to that in Section 3 and where B is scene brightness and transmission of the positive film

$$S_1 \propto B, \quad S_{1a} \propto S_1^\gamma \text{ i.e. } S_{1a} \propto B^\gamma, \quad S_2 \propto S_{1a}^{1/\gamma} \text{ i.e. } S_2 \propto B, \quad S_3 \propto S_2^\gamma \text{ i.e. } S_3 \propto B^\gamma \quad (12)$$

Now the type of photocell used has a high-gain electron multiplier built into its envelope and, neglecting dark current, the noise power is proportional to the incident light flux which is, in turn, proportional to the film transmission or scene brightness, B . The r.m.s. noise is therefore proportional to $\sqrt{B}$. Thus we have

$$N_1 \propto B^{1/2} \quad (13)$$

Substituting proportionalities 12 and 13 into 7, 8 and 9, we find that

$$N_3 \propto \gamma B^{\gamma-1/2} \quad (14)$$

If we let $\gamma = 2/5$ we see that N_3 is nearly constant, that is, the noise sensation is almost uniformly distributed over the grey scale as it was in the case of the high-velocity camera, although from different causes.

It is interesting to examine the behaviour of the noise when the same film scanner is used to transmit from negative film as distinct from positive. In this case the negative film may be assumed to have a gamma of about -0.7 . Fig. 7 shows the processes through which the signal and noise must pass in this case. With the notation shown in the figure we have, if B is the original scene brightness

$$S_0 \propto B^{-0.7}, \quad S_1 \propto S_0 \text{ i.e. } S_1 \propto B^{-0.7}, \quad S_{1b} \propto S_1^{-\gamma/0.7} \text{ i.e.} \\ S_{1b} \propto B^\gamma, \quad S_2 \propto S_{1b}^{1/\gamma} \text{ i.e. } S_2 \propto B, \quad S_3 \propto S_2^\gamma \text{ i.e. } S_3 \propto B^\gamma \quad (15)$$

and, similarly to proportionalities 7, 8 and 9

$$N_{1b} \propto N_1 \frac{dS_{1b}}{dS_1} \quad N_2 \propto N_1 \frac{dS_2}{dS_{1b}} \quad N_3 \propto N_2 \frac{dS_3}{dS_2} \quad (16)$$

Substituting 13 and 15 into 16 we obtain

$$N_3 \propto -(\gamma/0.7) B^{\gamma+6/5} \quad (17)$$

If we let $\gamma = 2/5$ we see that the noise sensation is proportional to the 8/5ths power of the scene brightness. This may be a serious disadvantage in the use of direct-negative transmissions; the noise would be highly concentrated towards the "white" end of the grey scale.

5. USE OF FILM SCANNER WITH LOW-GAIN PHOTOCELL⁴

Fig. 8 shows that for this type of photocell we regard the noise as originating entirely in the first stage of the head amplifier and thus assume that it is independent of signal or brightness level. This is by no means strictly true but will supply us with characteristics quite distinct from the case just treated in which we assumed the noise to be entirely dependent upon brightness. The practical case will lie between these two examples. Fig. 8 shows that this case is identical with that of the low-velocity camera treated in Section 3. It will be recalled (proportionality 11) that the noise sensation in that example increased in the "blacks". As was stated in the last paragraph of Section 3, the noise visibility could be rendered less obtrusive by applying de-gamma technique to the scene. In the case of film scanners, however, this would be quite possible although requiring non-standard film. Satisfactory results would be obtained with positive film having a 2/5ths gamma law.

The case of transmission from negative film is shown in Fig. 9. Using proportionalities 15 and 16 and remembering that, as in Section 3, N_1 is independent of B , we have

$$N_3 \propto \frac{-\gamma N_1}{0.7} B^{\gamma+0.7} \quad (18)$$

If $\gamma = 2/5$ we find that the noise sensation is proportional to the 11/10ths power of the brightness, which, although undesirable, is more evenly distributed than was the noise sensation when using a film scanner employing a high gain multiplier-type photocell for transmission from negative film. This may explain the superiority of the low-gain-photocell type of (Cintel) film scanner over the (E.M.I.) high-gain-photomultiplier model for direct-negative transmission.

6. USE OF CAMERA WITH LOW-VELOCITY BEAM: IMAGE-ORTHICON CAMERA⁵

This case must be regarded as very tentative because the operation of image-orthicon cameras depends greatly on electron-image re-distribution effects which convert a saturated static gamma characteristic into what amounts to a dynamic characteristic having an exponent of about 2/5. Let us assume, as seems probable, that the two-fifths power law which operates on the scene-brightness to charge-image transfer characteristic does not directly affect the noise in that the latter, being due to "shot" effect in the return scanning beam, is proportional to the half-power of the return-beam current. The signal-modulated beam current may itself be assumed to vary as the two-fifths power of the scene brightness.

Referring to Fig. 10 and using the notation shown there, we have, omitting reference to signal polarity,

$$S_1 \propto B^\gamma, \quad S_2 \propto S_1^{1/\gamma} \text{ i.e. } S_2 \propto B, \quad S_3 \propto S_2^\gamma \text{ i.e. } S_3 \propto B^\gamma \quad (1)$$

wherein we have let γ be representative of the approximate two-fifths power law between scene brightness and camera output; and, remembering that the noise is due to the return beam only,

$$N_1 \propto (1 - mS_1)^{1/2} \text{ or } N_1 \propto (1 - mB^\gamma)^{1/2} \quad (19)$$

where m is the depth to which the return beam is modulated by the signal current.

Putting 1 and 19 into 3 and 4 we find that

$$N_3 \propto (1 - mB^\gamma)^{1/2} \quad (20)$$

If we let $m = 1/2$, $\gamma = 2/5$ we find that the noise sensation increases very slightly towards the dark parts of the scene. From a practical viewpoint the noise may be regarded as uniform over the grey scale in that it varies by $\sqrt{2}$ to 1 in sensation units from black to white.

7. CONCLUSIONS

A number of television channels have been examined and the following conclusions may be drawn:

- (i) Unity-gamma pick-up devices, whether they be cameras or film scanning equipment, distribute the sensation of noise unevenly over the "tone" range of the picture unless the de-gamma device required to ensure correct "tone" reproduction can be placed in the initial light path and thus precede the noise. This conclusion is restricted to picture originating equipment in which the noise is added to the picture signal in such a way as to be independent of it at the place of addition. Orthicon cameras and flying spot film scanners with low gain photocells are examples to which this conclusion is applicable.
- (ii) Greater sensitivity expressed in microampères per lumen does not assure superiority as regards signal-to-noise ratio. If a camera suffers from a restriction upon the total permissible studio lighting due, for example, to target instability, then another camera which has no such limitation can be illuminated to such a value as to ensure a signal-to-noise ratio superior to that of the former.
- (iii) As a corollary to (i) it is possible to ensure uniform distribution of noise sensation in the case of a flying spot film scanner using a low-gain photocell by insisting upon the use of low-gamma ($\gamma \approx 2/5$, say) positive film and removing the "post noise" de-gamma circuit required for transmission of normal, unity-gamma positive film.
- (iv) Flying spot film scanners using high-gain photomultiplier tubes ensure a near-uniform noise sensation distribution and are therefore to be preferred to the other type. The former type of film scanner, however, transmits negative film (with appropriate negative-gamma circuits) with a distribution of noise sensation which is biased heavily towards the lighter "tones" in the picture; that is, it is "noisy in the whites". A film scanner using a low-gain photocell will transmit negative film (again with appropriate negative-gamma circuits) with a better distribution of noise sensation. It will still be noisy in the whites, but relatively less so

than in the case of a film scanner using a high-gain photomultiplier tube. It should be remembered, however, that the high-gain photomultiplier will give rise to a greater signal-to-noise ratio than will the low-gain photocell in spite of the more even noise distribution of the latter.

- (v) The image orthicon camera is a unique case in that it generates its own noise and the distribution of noise sensation in the final picture is nearly uniform, being about $\sqrt{2}$ times greater in the "blacks" than in the "whites".

8. REFERENCES

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APPENDIX

SOME MEASUREMENTS ON A (CINTEL) FILM SCANNER USING LOW-GAIN PHOTOCELL

Section 5 has dealt with a film scanner using a low-gain photocell, and a certain (Cintel) film scanner fits into this category fairly well. In this connection some measurements on tone reproduction and noise may be of interest. The measured overall transfer characteristic is shown in Fig. 11. This gives the relative brightness of the reproduced image against the relative transmission of the film. Using the sensation vs. brightness curve shown in Fig. 2* it is a simple matter to recalculate the transfer characteristic in the form of sensation units and this is shown in Fig. 12. It will be seen that fairly good linearity of tone reproduction is obtained, except that the near-black tones have been over-accentuated.

The effect of noise in this film scanner was estimated as follows: The noise level as displayed by the waveform monitor was measured at various signal levels: in actual fact the voltage excursions indicating noise were found to be approximately constant throughout the tone range from black to white. This constant voltage excursion applied to the cathode-ray-tube transfer characteristic and thence to the sensation curve (Fig. 2) gave a set of noise values in sensation units which have been plotted in Fig. 13. Although this curve has no simple mathematical equivalent, it is obvious that the noise in the "blacks" is much more apparent than in the lighter tones, and is in general agreement with the result given by the simplified treatment in Section 5 of the main text.

It should be pointed out that Fig. 13 shows both scales in sensation units, i.e. both noise sensation and brightness sensation: in contradistinction the proportionalities evaluated in the main text quote noise in sensation units vs. brightness measures on an objective physical (non-sensation) basis.

*This curve is deduced from Fig. 16 of "Colour Reproduction by Colour Photography", F.I.A.T. Final Report No. 977 (H.M.S.O.). It is similar to curves quoted by L.A. Jones, Phot. Journal, 89B/131/1949, and R.G. Hopkinson, Phot. Journal, 91B/4/1951.

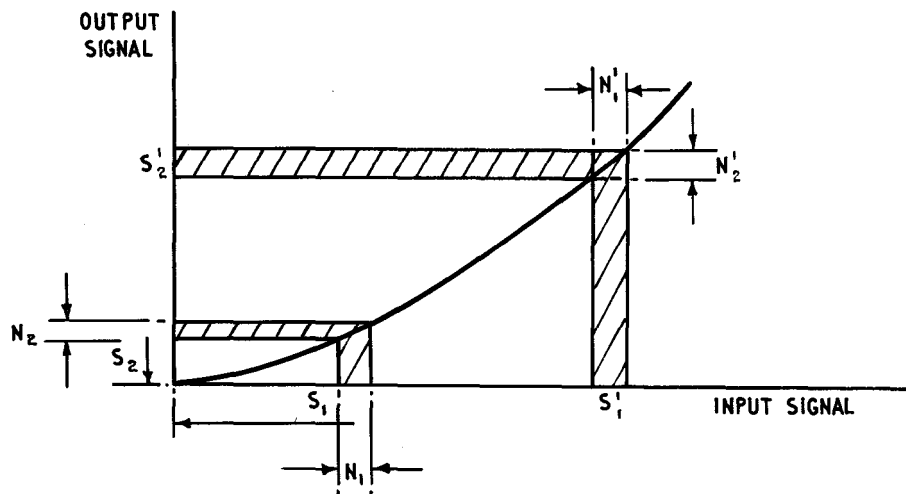


Fig.1

Effect of non-linear circuit on signal and noise.

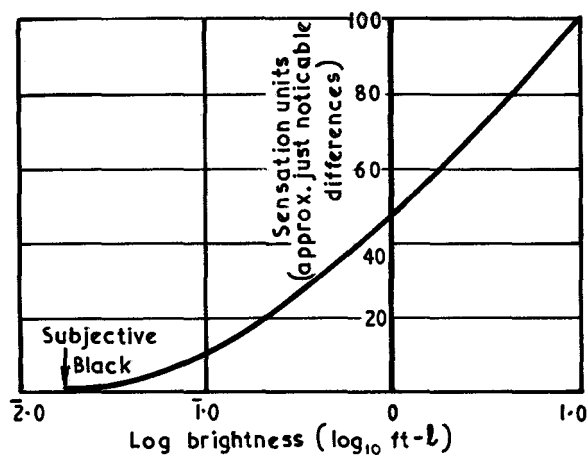


Fig.2

Sensation scale for the eye with a surround brightness of 1 ft-l

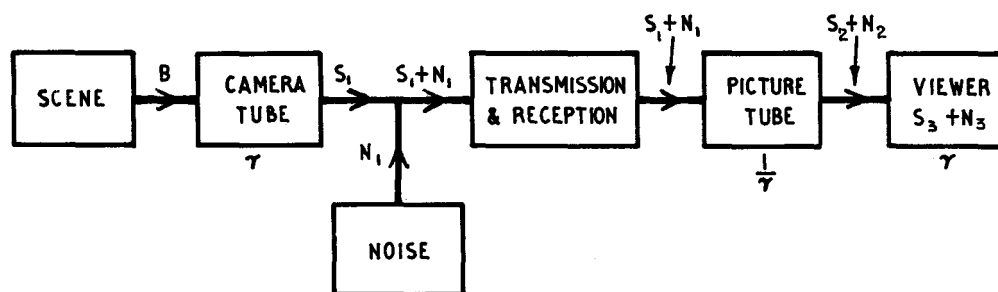


Fig.3

Television transmission using high-velocity camera.

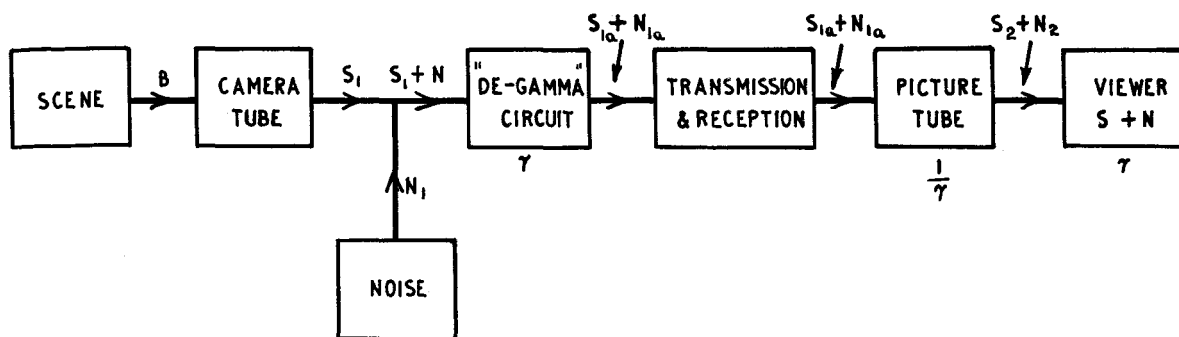


Fig. 4

Television transmission using low-velocity orthicon camera.

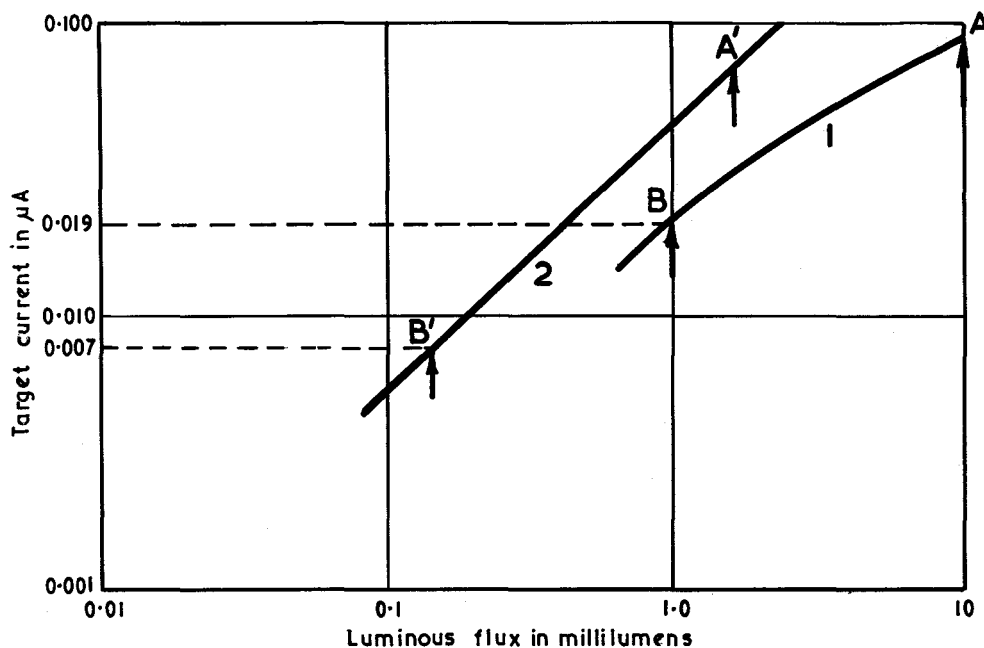


Fig. 5

Comparison between cameras with linear & non-linear transfer characteristics.

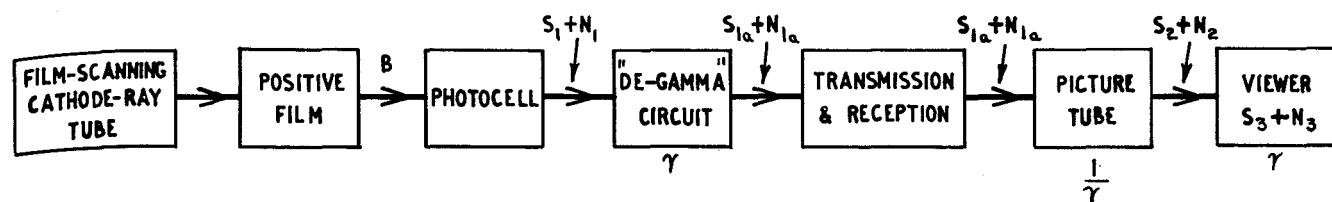


Fig.6

Television transmission with film scanner using high-gain photo-multiplier.

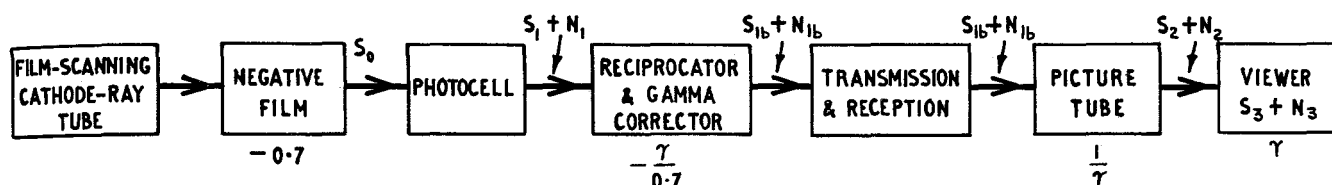


Fig.7

Television transmission from negative film with film scanner using high-gain photo-multiplier.

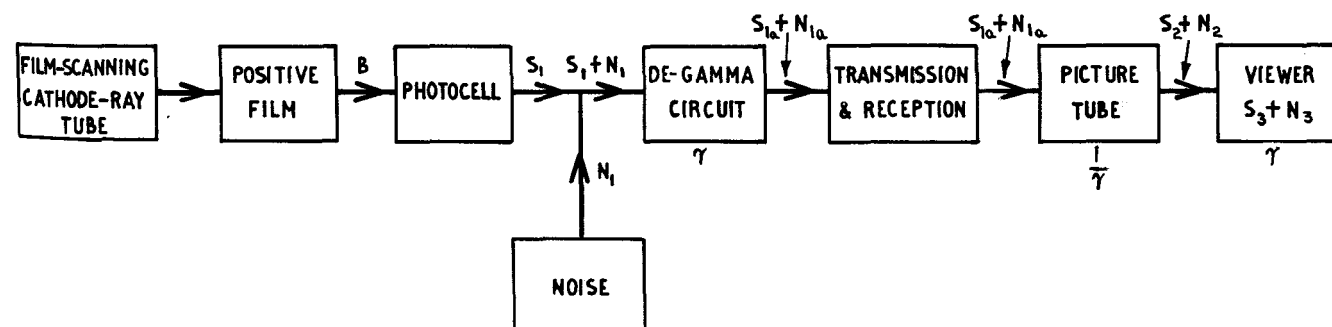


Fig.8

Television transmission with film scanner using low-gain photocell.

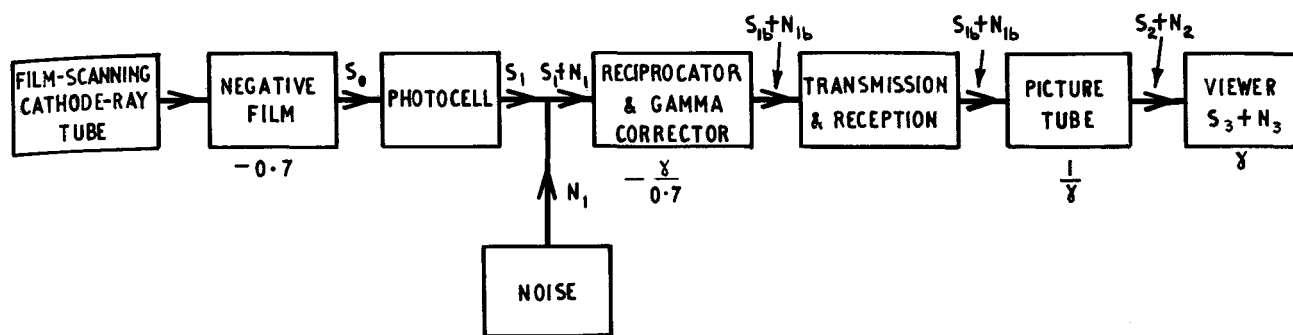


Fig.9

Television transmission from negative film with film scanner using low-gain photocell.

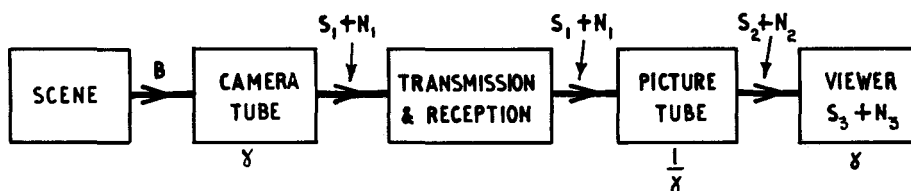


Fig.10

Television transmission using low-velocity image-orthicon camera.

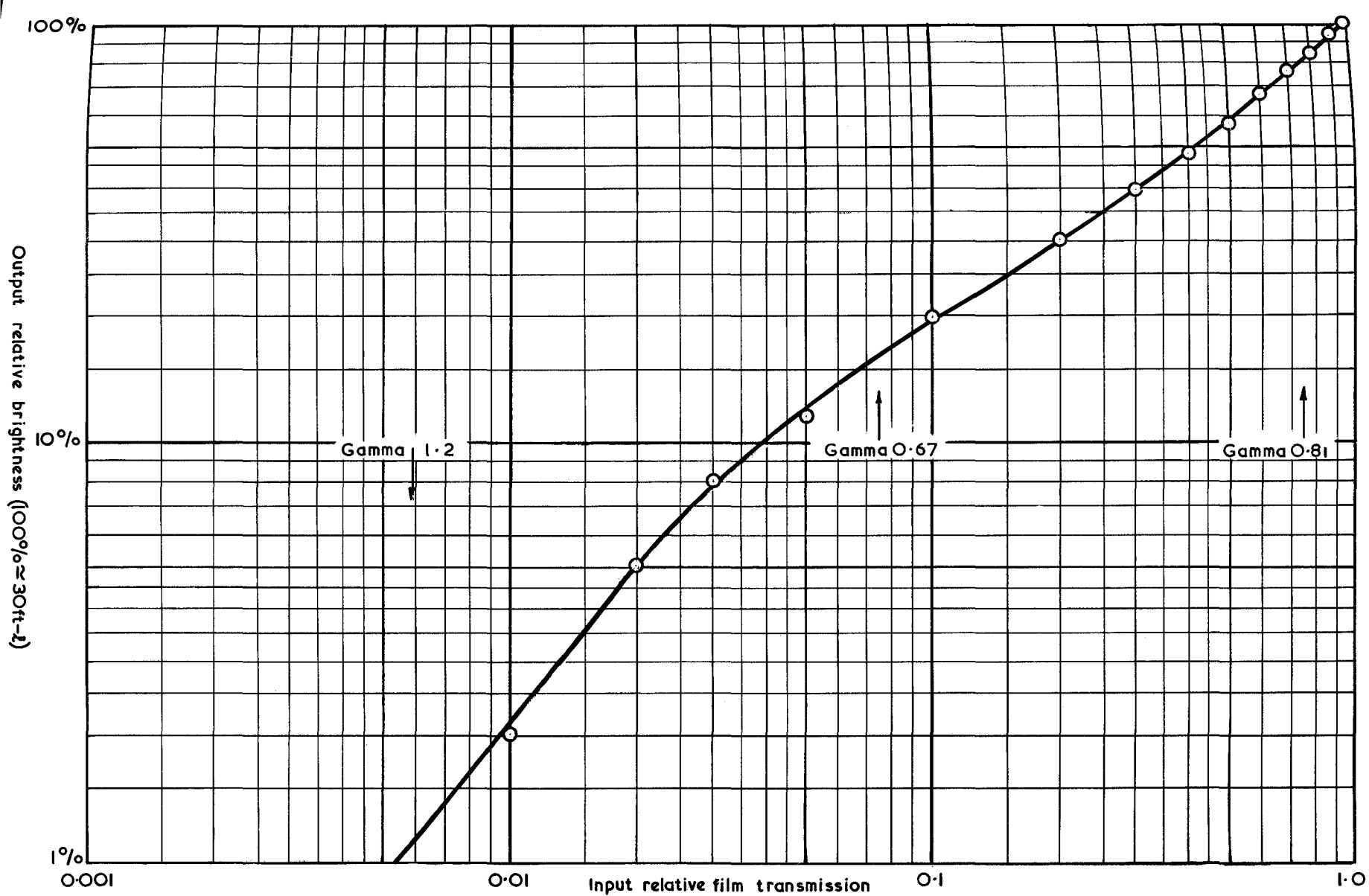


Fig. II
Overall characteristic of Cintel Telecine
(photocell-gamma circuit - CRT)

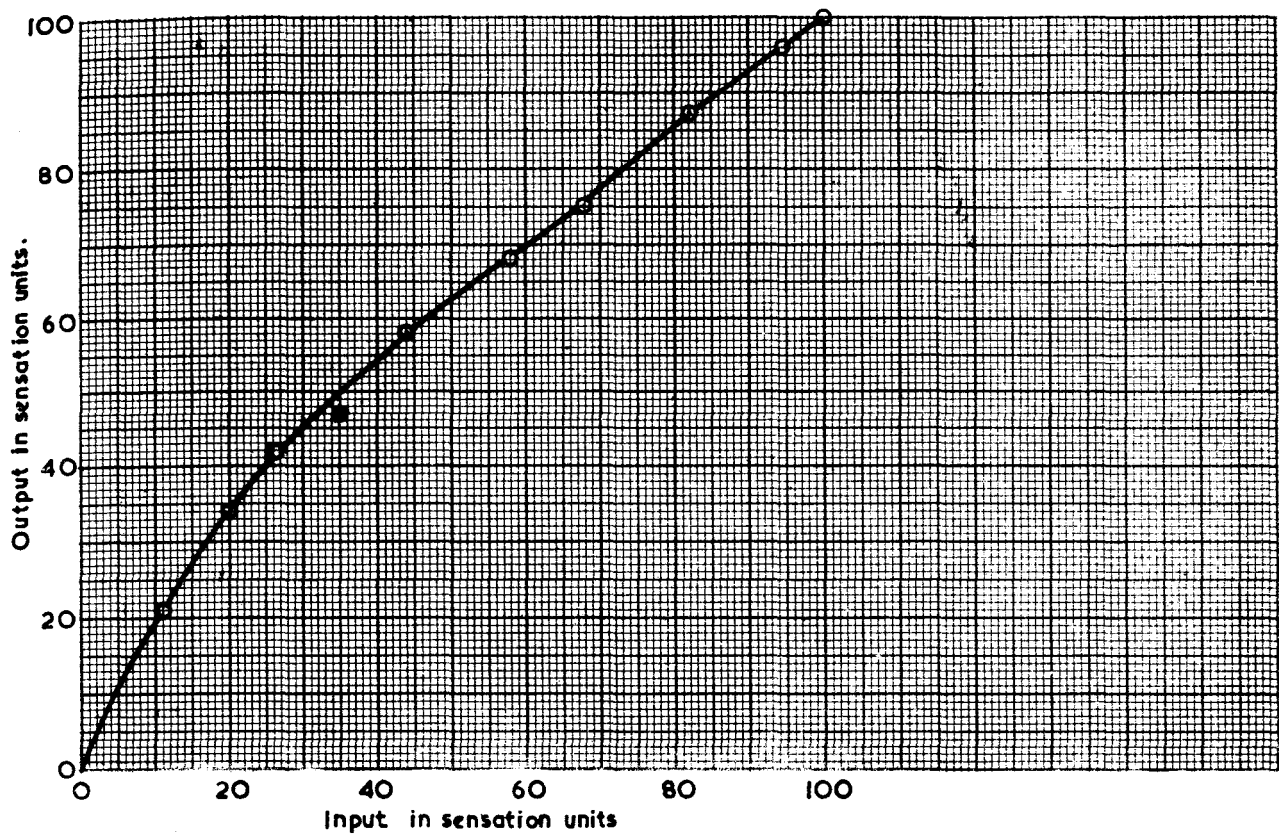


Fig.12

Overall transfer characteristic of Cintel Telecine.

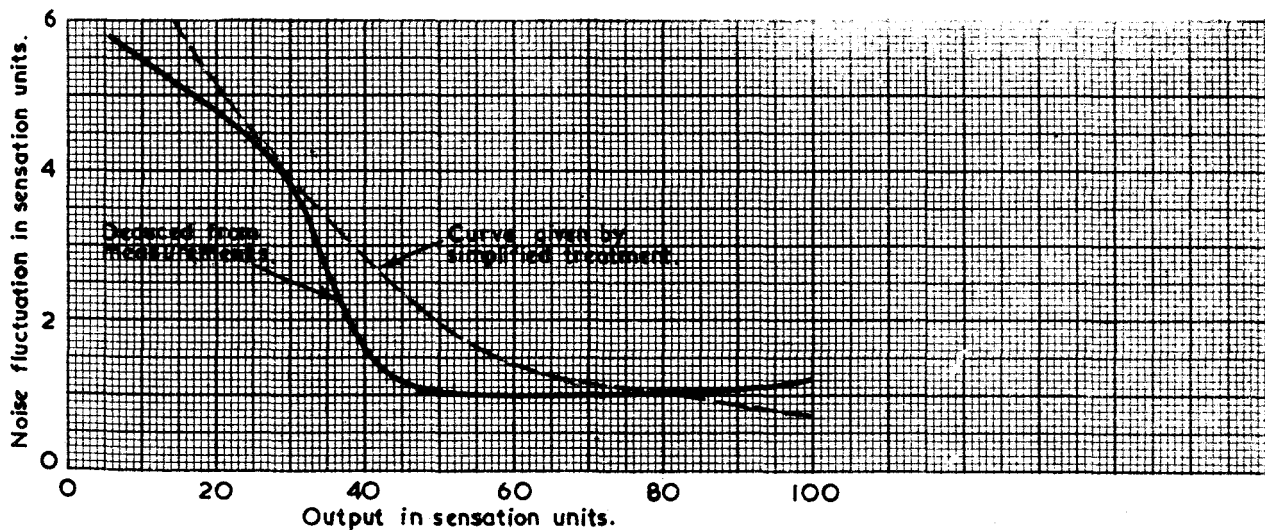


Fig.13

Noise/output characteristics.